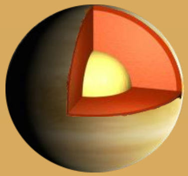
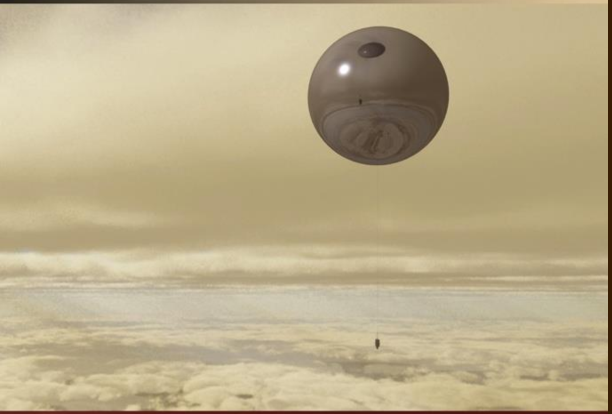
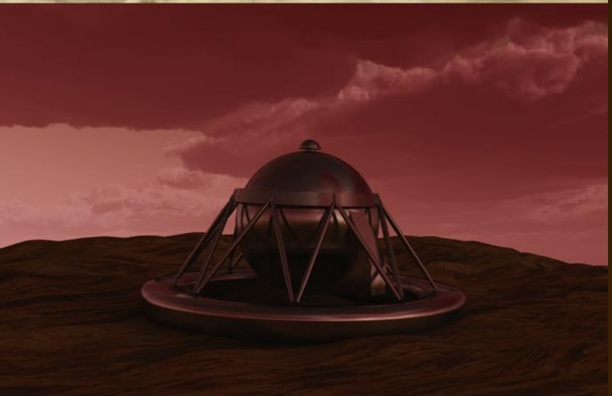






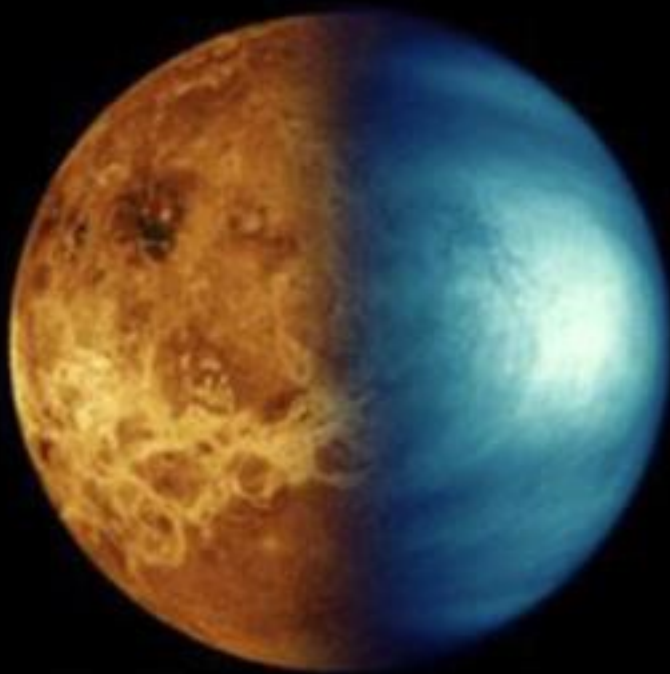
Venus Aerial Platforms and Engineering and Scientific Modeling Needs

James Cutts[1], Larry Matthies[1] & Thomas W. Thompson [1]
and members of the Venus Aerial Platform Study Team

Venera-D Modeling Workshop
Space Research Institute
Moscow, Russia
October 5-7, 2017

1. Jet Propulsion Laboratory, California Institute of Technology

Venus and Earth – Planetary Siblings



Magellan Galileo

Apollo 17

Planetary Science Vision 2050 - Venus

- In February 2017, the Venus Exploration Assessment Group (VEXAG) outlined a strategy for Venus Exploration through 2050.
- A key element of that strategy was a Roadmap for the role of Aerial mobility in Venus Exploration.
- In March 2017, NASA’s Planetary Science Division initiated a study to refine this initial roadmap and to identify the key technologies needed to implement it
- The study involves participants drawn from NASA Centers, industry and universities and two 3 ½ day study team meetings
- This is a status report and covers highlights from the first study team meeting which was held at Caltech May 30 to June 2.

Venus Exploration Modes
Increasing degrees of difficulty

- Flyby
- Orbiter
- Descent Probe
- Land-short duration
- Float - Upper atmosphere
- Fly – Upper atmosphere
- Land- long duration
- Rove – with aerial mobility
- Sample Return – Cloud
- Sample Return - Surface

Venus Atmospheric Environments

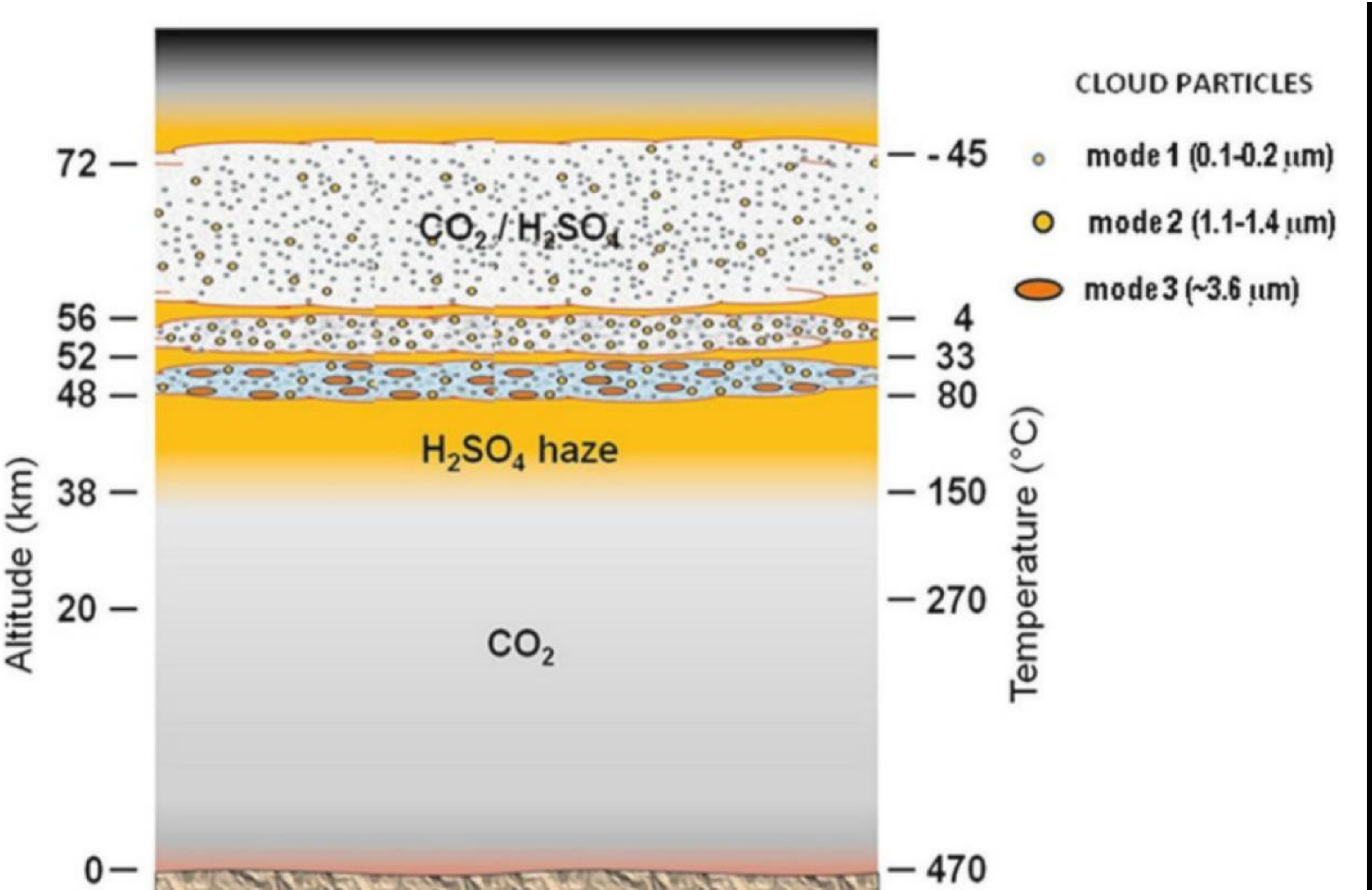


Image Credits : S. Makuch, Cosmic Biology (2011).

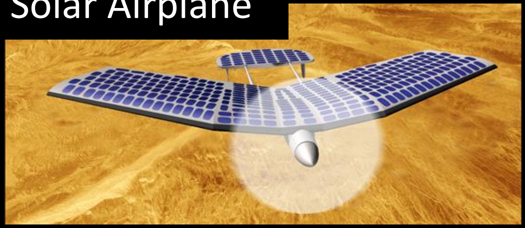
VEXAG - Aerial Mobility Roadmap

Superpressure Balloon

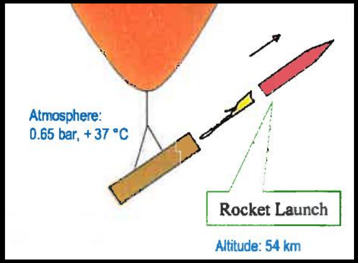
Lateral mobility

Hybrid Airship (VAMP)

Solar Airplane

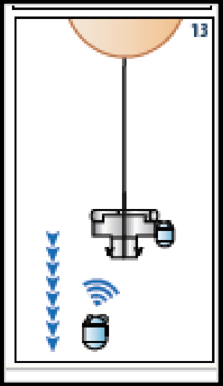


Surface and Cloud Particle Sample Return



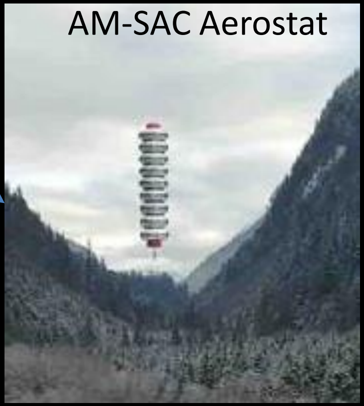
In Situ Sample Analysis @ 54km)

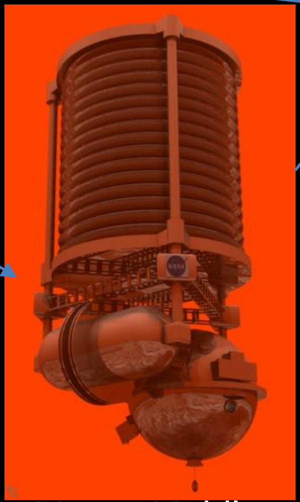
DEPLOY PROBES AND SONDES



Altitude Control

AM-SAC Aerostat





Venus Mobile Explorer

Dual Balloon concept for raising Venus Surface Samples to 55 km altitude

Near Term

Mid Term

Far Term

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Venus Aerial Platforms Study - Approach

- Initial Planning
  - Frame the approach
  - Assemble an expert team
  - Conduct three telecons with study team
- First study team meeting – May 30 to June 2 2017
  - Scientific opportunities offered by aerial platforms at Venus,
  - Environments that aerial platforms must content with
  - Capabilities of alternative aerial platform technologies
- Second Study Team Meeting
  - Feasibility of options identified in the first meeting
  - Maturity of extreme environment technologies
  - Mission design and architecture
- Formulate the roadmap and technology plan – target Jan 2018

First Study Team - Participants

- Michael Amato, NASA Goddard SFC
- Kevin Baines, U. Wisconsin,
- Maxim De Jong, TRL Aerospace
- Mona Delitsky, CSE, Pasadena
- Lori Glaze, NASA Goddard SFC
- Bob Grimm, SwRI, Boulder
- Jeffery Hall, JPL
- Attila Komjathy, JPL
- Tibor Kremic, NASA Glenn RC
- Geoffrey Landis, NASA Glenn RC
- Sebastien Lebonnois, LMD, France
- Sanjay Limaye, U. Wisconsin
- Kevin McGouldrick, U. Colorado
- Kerry Nock, Global Aerospace
- Peter Ngo, Global Aerospace
- Michael Pauken, JPL
- Danny Sokul, Northrop Grumman
- Gerald Schubert, UCLA
- David Senske, JPL
- Tom Spilker, Consultant
- Paul Steffes, Georgia Tech
- Eugene Ustinov, JPL
- William Warner, JPL
- Steve Warwick, Northrop Grumman

Includes experts in the Venus science (atmosphere, surface and interior) and the capabilities of aerial platforms and mission design and architectures

VEXAG Goals and Objectives for Venus Exploration

Atmosphere	Surface & Interior	System Interactions & Water
• How did the atmosphere form and evolve? • What controls the atmospheric super-rotation and greenhouse? • What is the impact of clouds on climate and habitability?	• How is heat released from the interior and has the global geodynamic style changed with time? • What are the contemporary rates of volcanism and tectonism? • How did Venus differentiate and evolve over time?	• Was surface water ever present? • What role has the greenhouse had on climate history? • How have the interior, surface, and atmosphere interacted as a coupled system over time?

Science – Atmosphere

- Altitude control makes it possible to characterize and understand the atmospheric super-rotation and global circulation, by measuring the zonal and meridional wind structure over the range of accessible altitudes
- Altitude control provides a unique opportunity to probe below the lower cloud deck to haze layer to a region where heating rates is not accounted for by current models
  - Measure temperature profile, haze optical properties below clouds and wave activity.
  - If practical make precise measurements of net flux to constrain heating rates to improve circulation model.
- Altitude control can make it possible to characterize the Hadley cell structure.
  - Primary observables are position and velocity
  - Important scientifically and for designing trajectories to optimize mission life
- Altitude control can also enable exploration of the UV absorbing layer.
  - Key observables are particle size and composition as a function of altitude.
  - Need to define what is the minimum altitude range that will do the job
- Probe measurements of the deep atmosphere are needed
  - To confirm nitrogen deficiency within 7 km of the surface
  - To investigate any other departures from uniform mixing
  - To understand forces exerted on the planetary surface by the atmosphere

Science - Surface and Interior

- Substantial geophysics-related science feasible from aerial platform operating in regions of benign temperatures.
  - Huge improvement in quality of data by being closer to surface (i.e. below orbit);
  - Performance gain achievable with still lower altitude.
  - Magnetic field, Schumann resonance, and gravity are of interest

- Measurements of atmospheric pressure and frictional forces on Venus combined with radar measurements of variations in the length of the day may provide the means of determining the M of I and hence the deep structure of Venus (II.A.2)[1]

- Visible imaging of surface is of interest, but requirements need clarification
  - Need platform within 106 km of the surface
  - IR will be challenging at low altitudes because of the temperatures

- Potential for infrasound-based detection of seismic activity
  - Can detect seismic activity at a low level
  - Need to understand ability to probe interior from aerial platform measurements

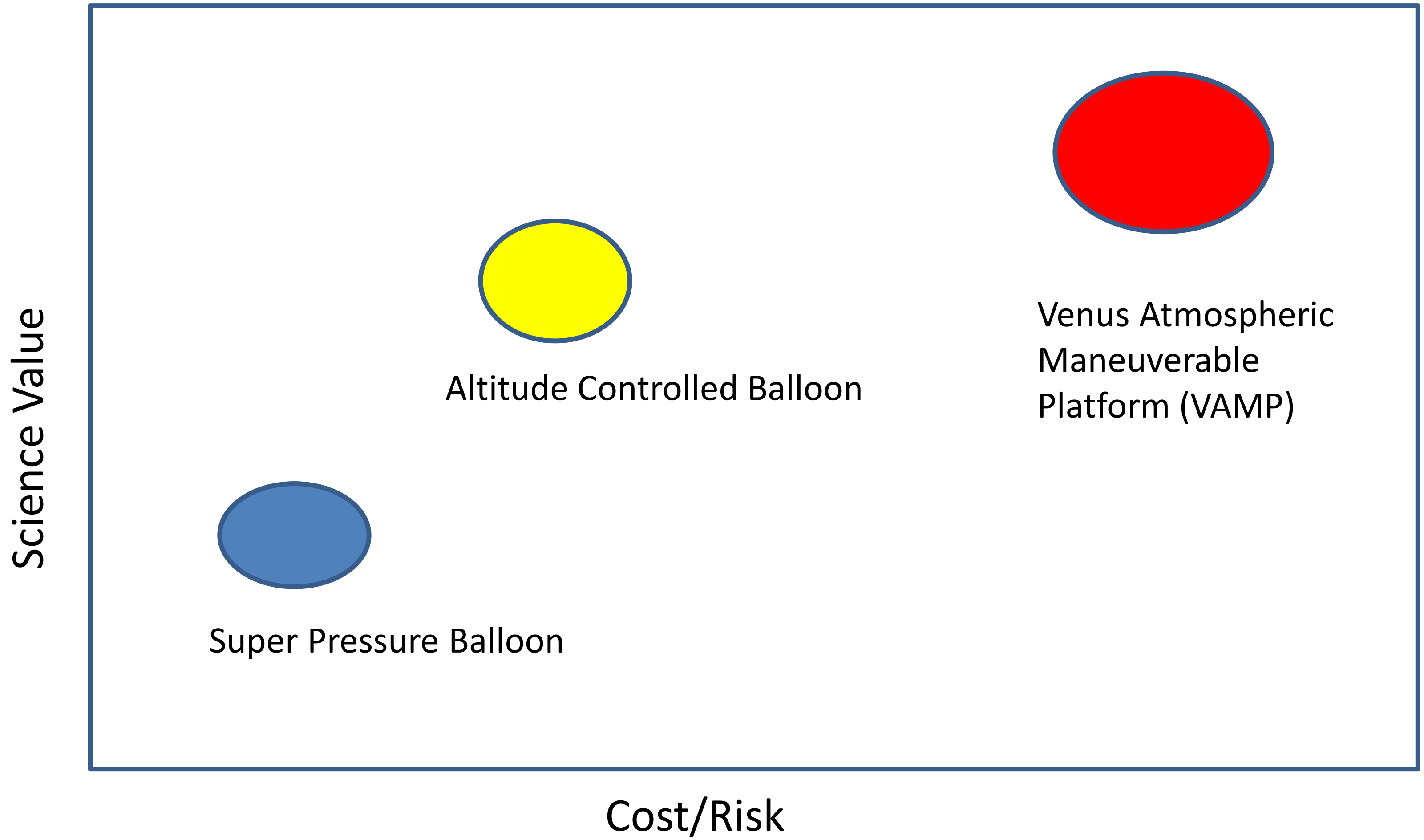
1. Designation refers to [VEXAG Goals Objectives and Investigations for Venus]

Science - Surface Atmosphere Interaction

- Access to lowest part of the atmosphere with probes, sondes or other very low altitude aerial platforms can enable key GOI objectives
  - Identification and characterization of any areas that reflect formation in a geological or climatological environment significantly different from present day
  - Current rate of sulfur outgassing from the surface
- Objectives in the GOI requiring measurement of noble gases and stable isotope ratios in the atmosphere are feasible
  - Long integration times could permit greater precision
  - Altitude control could enable test of whether ratios are altitude independent
- Geophysical investigations of interior-surface- atmosphere interaction (II.B.5) can help understand the mechanisms controlling the superrotation, Venus rotation and Venus interior structure.
  - Understanding atmospheric torques on the planet pressure and frictional. Including observations of the bow wave in situ and it time of day dependence?
  - Couple this with radar measurements of Venus rotation rate variation from Earth or orbit

Aerial Platform Cost-Benefit Trend

- The work to date suggests a science value versus cost and risk situation illustrated below:
  - Continued analysis will explore the suggestion that altitude-controlled balloons may be in the "sweet spot".



Science - Summary

- The importance of altitude control is a strong common thread running through all three science areas.

- Horizontal position control does not appear to be as critical
  - Altitude control will enable moving in and out of different airmasses
  - Fine positional control not a high priority at this time
  - Adequate positional knowledge both desirable and achievable
  - Positional control sufficient to overcome meridional drift would be desirable

- Probes that can enter and operate in the lower 10 km of the atmosphere are also a priority
  - Short life time probes can carry out the most complex measurements
  - Long lived probes will require development but sensors will be limited in what they can measure to pressure, temperature, acceleration etc.

More Information

For more information visit
http://www.lpi.usra.edu/vexag/